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A.R.D.E. REPORT (B) 7/61

Direct fire control with the Ranging Machine Gun:
an analysis of the errors involved

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Fort Halstead,
Kent

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A.R.D.E. REPORT (B) 7/61

Direct fire control with the Ranging Machine Gun: an analysis of the errors involved

R. Beresford (B5)

Summary

An analysis is made of the errors affecting the use of the Ranging Machine Gun (RMG) system of direct fire control and an examination of their effect on the chance of hit of the 105 mm. tank gun carried out.

It is concluded that when used with the APDS projectile the RMG and coincidence range-finder do not offer much advantage one over the other but both show an increase of 20 - 30 per cent in first round chance of hit compared with that given by visual range-finding. It is also shown that with the HESH projectile, the RMG provides considerable improvement in first round chance of hit over visual range-finding, and gives a general increase of about 20 per cent over that obtained using a coincidence range-finder.

Approved for issue:

D.H. Black, Director

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INTRODUCTION

1. The Ranging Machine Gun (RMG) fire control system is being developed for use in the up-gunned Centurion tank (105 mm. APDS and HESH) and the new medium tank Chieftain (120 mm. APDS and HESH). In order that the effect of changes in gun and projectile parameters on chance of hit may be explored, and that the system may be compared with other fire control systems, an analysis of the errors involved has been carried out and their effect on the performance of the 105 mm. tank gun examined.

DESCRIPTION OF METHOD

2. The development of fire control with the RMG has been described earlier (1) (2) (3) (4) (5) and the various techniques discussed at length. Basically the method consists of firing a sub-calibre gun (usually a 0.5 in. machine gun) at increasing elevations until strikes are observed on the target or the target is bracketted, inferring the target range from the ballistics of the sub-calibre round, and firing the main armament using the information obtained. As the development has proceeded, certain variations in the techniques have emerged as giving the optimum results with the main armament envisaged and it is with these preferred techniques rather than the historical developments that this report is concerned. The proposed methods are now described in detail under the heading of the relevant main armament projectile.

APDS

3. Owing to the flat trajectory of this high velocity projectile it has been found unnecessary to know the precise range to target in order to obtain a high chance of hit. Range errors of as much as 150 yards can be tolerated without serious degradation in hit probability. Consequently it is possible to simplify the ranging with the sub-calibre round(3) because it is sufficient to know that the target lies within a certain range band.

4. Briefly, a ballistic graticule in the sight is used to fire the machine-gun at various elevations specified by range marks (Figure 1) which will be numbered 1-4 for convenience. Bursts of three shots are fired in order using these marks which correspond, say, to ranges (1) 980, (2) 1350, (3) 1650, (4) 1860 yards. If the bursts up to mark 3 are short of the target and that using mark 4 is over, then, subject to an error which is dependent on the machine-gun dispersion it is established that the target lies within the range band 1650-1860 yards. To make use of this information another ballistic graticule for the APDS round is included in the sight consisting of a further five dots corresponding to ranges which lie either at the midpoints of the machine-gun range bands or at some position weighted to give the best performance, say (1) 800, (2) 1200, (3) 1525, (4) 1785 and (5) 1975 yards. Hence, in the example considered here, if a plus with mark 4 for the RMG indicated that the target lay between 1650 and 1860 yards, then the firing of the APDS round using its own dot 4 would be accompanied by an error in range of less than 75 yards at one end of the band and less than 135 yards at the other.

5. To summarise the procedure, the gunner fires four successive bursts with the RMG using the specified graticule dots, associates the particular dot which first gives an over-burst with the appropriate APDS dot, and fires the main armament. If all the bursts are short, it is assumed that the target is at a range of 2,000 yards and APDS dot 5 is used.

HESH

6. The selected method of controlling the fire of this projectile is basically similar to that for APDS with additional factors. It is found that if the machine gun is depressed through some constant angle relative to the

main armament then the trajectories of the two rounds, machine-gun and HESH can be matched effectively over most of the fighting range to within narrow limits.

7. As the trajectory of the HESH round is considerably less flat than that of the APDS round, the ranging technique must be refined to give more accurate information. In practice a compromise between speed into action and accuracy is made in the following manner.

8. The gunner lays RMG marks 1-4 on the target and fires the usual RMG burst of three shots with each mark. When the first plus is observed, he lays the next graticule mark down (Figure 1) 100 yards less in range and first again. If this burst is still over the target the next graticule mark 100 yards less is employed. If any of these bursts hit short of the target, or the strikes are still over when using the 100 yard mark nearest to the numbered dot which gave the last minus, then the range to target is known to within 100 yards within the limits of the RMG dispersion. The gunner then lays on the target using a graticule position half-way between the two 100 yard marks which gave under-or over-bursts respectively, and fires the main armament. The same ballistic graticule is used for all these operations. Naturally if a central hit with the RMG is obtained using one of the 100 yard graticule marks, then that mark will be used to fire the main armament.

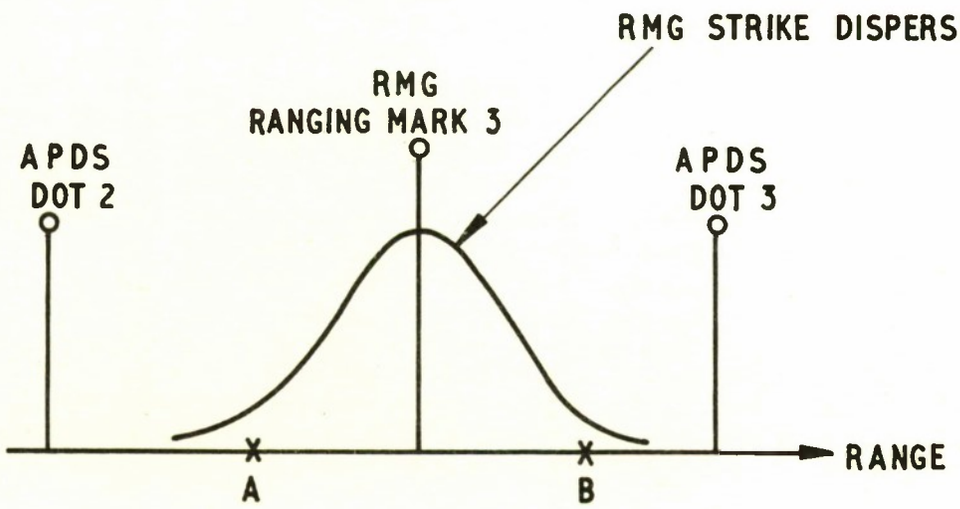
ERRORS ARISING FROM THE TECHNIQUES

APDS

9. The errors resulting from the combination of the multi-burst technique with the high velocity APDS projectile are two in number. Firstly, there is a direct error in range arising from the use of a particular main armament graticule dot covering a range band instead of the true range. For example, if the true range to the target is 1270 yards, the RMG would indicate that the 1200 yard APDS graticule dot should be used resulting in a range error of 70 yards. The error is zero at the ranges corresponding to the APDS dots and rises to a maximum at points between them and dependent on their location. This error has the effect of a permanent bias and is always present in the weapon systems considered.

10. The second source of error is an occasional one and is the possibility of taking a different APDS graticule dot from the one properly corresponding to the range band concerned. It is purely a function of the overall dispersion of the RMG and can only occur at certain ranges near to those corresponding to the RMG graticule dots and then only on a small percentage of occasions.

11. There are four ways in which this error can manifest itself (see diagram below)



Firstly, if the target is at position A, which can be anywhere between the mark range and the left-hand side of the strike distribution, there is a finite probability, dependent on the RMG dispersion, that all three shots in the burst will fall short of the target range. When this occurs, the gunner, having fired the RMG on the next mark up and obtained a plus, will select APDS dot 4 when he should have taken dot 3.

12. Secondly, if the target is at position B, which may be anywhere between the RMG mark range and the right-hand end of the distribution, there is a possibility that all three shots in the RMG burst will fall past the target, in which case the gunner will choose APDS dot 2 when dot 3 should have been taken.

13. Thirdly and fourthly, there are the occasions when the RMG burst straddles the target and a "hit" is obtained. If the target is at position B, (anywhere on the right-hand side of the distribution), this will result in, say, APDS dot 3 being used instead of dot 4, the correct one. The two occasions on which this may occur are:

(a) one strike over and two under, and

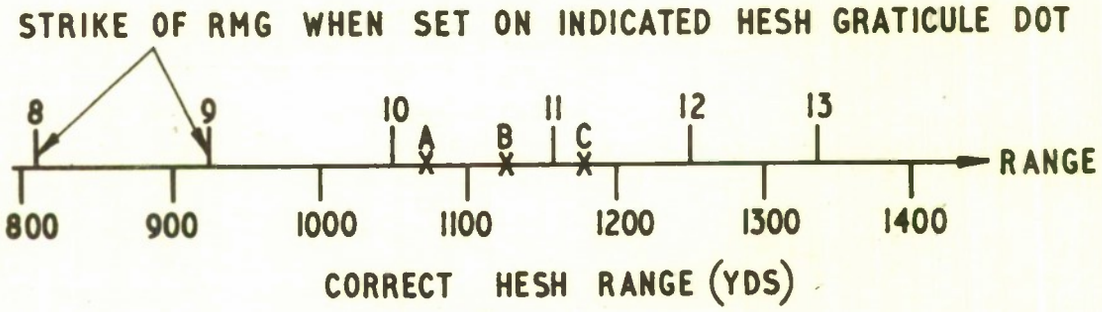
(b) two strikes over and one under.

The resulting probability distributions, based on a range dispersion of 17 yards S.D., the current estimate of the 0.5 in. Browning Machine Gun performance, are shown in Figure 2.

HESH

14. The fire control errors which affect the HESH projectile when directed by the RMG are three in number. The first is a possibility of taking a different dot to the one intended by the techniques, a similar type of error to that affecting the APDS-RMG combination.

15. The remaining two are (a) a range error arising from the use of discrete range bands as in the APDS case and (b) the error arising from the horizontal difference in matching between the HESH and RMG projectiles. These errors may be appreciated in the following diagram.



16. The difference between the RMG point of strike and the true HESH range represents the horizontal mismatch between the trajectories of the two projectiles.

17. If the target is at position A at a true range of 1080 yards the gunner, having fired the RMG on mark 10 and registered a minus, will then fire with marks 13, 12 and 11 in succession. As all these bursts are plus of the target, he knows that the target lies between the RMG "ranges" 1000 and 1100 yards. He then fires the main armament with a graticule setting of 1050 yards resulting in a range error of 30 yards.

18. If the target is at position B at a true range of 1130 yards, the gunner will still fire with a point on the HESH graticule corresponding to 1050 yards range; the resulting range error of 80 yards will correspondingly lower the probability of hit. When the target is at position C at a range of 1120 yards, however, a straddle is observed with RMG marks 11 and 12 and a range of 1150 yards is applied with a range error of 30 yards. This change in range error results in an increase in chance of hit at this range over that at point B, although the range is greater.

FIRST ROUND CHANCE OF HIT WITH THE 105 MM. TANK GUN UNDER QUASI-BATTLE CONDITIONS

19. First round chances of hit against a 7 ft. 6 in. square target for the APDS and HESH projectiles fired under quasi-battle conditions have been calculated using generally agreed Tripartite methods(6) (7). Three types of range estimation are considered, the Ranging Machine Gun, the coincidence range finder, and visual estimation. In addition, the chance of hit with zero range error is given for comparison purposes.

20. For the coincidence range-finder a standard deviation of $15R^2$ yards (where R is in thousands of yards) has been used, the order of accuracy to be expected from the type of instrument which might be accommodated in AFV's, and a standard deviation of 30 % of the range used for the error resulting from visual range finding. The characteristics of the projectiles considered here are shown in Table 1 below, and the component error values used in the chance of hit calculations listed in the Appendix.

Table I

	0.5 inch Ranging Machine Gun	105 mm. Tank Gun	
Projectile	Incendiary Tracer	APDS	HESH
M.V. (f/s)	3060	4800	(2300 (2400
C_o	0·38 (1940)	1.86 (1940)	1.375 (1910)

APDS

21. The chance of hit calculations with this projectile are summarised in Figure 3. In the RMG values it will be seen that the chance of hit does not decrease regularly with range but varies from maxima coincident with the curve of zero range error, to minima at several points on the range scale. This oscillation is a characteristic of the multi-burst technique of ranging, where a specific range is used to fire regardless of where the target is in the particular range band. Thus, in the example considered, the maxima correspond to points where the gun is fired with the exact range to the target and the minima occur where this range error is at its greatest. For example, if the target is at a range of 1645 yards, RMG dots 2 and 3 will bracket it and, therefore, APDS dot 3 will be used to fire the main armament with a range error of 120 yards. When the target true range is increased to 1680 yards, APDS dot 4 will be indicated which gives a range error of 105 yards and a relative increase in chance of hit which continues until the next maxima is reached at a range of 1785 yards.

22. No allowance has been made for a trunnion tilt correction with these results. A method is under development, however, which provides certain compensations. Essentially, if the tilt is greater than 5° at ranges greater than 1500 yards (or for APDS dots 4 and 5) then the gunner corrects by aiming at the edge of the target appropriate to the direction of tilt. The result of this allowance of half-a-target is to improve the first round chance of hit at the longer ranges, e.g. with a tilt of 10° the first round chance of hit at 2000 yards with APDS is increased from 15% (uncorrected) to 45% (corrected).

HESH

23. The chances of hit resulting from the application of the principles discussed earlier are shown in Figures 4 and 5. Two velocities are considered for the HESH projectile, 2400 and 2300 f/s. In view of a possible effect of barrel wear on the muzzle velocities of the two guns, two stages in gun life have been considered (a) both new, and (b) both part-worn, for which the conventional period to the end of the first quarter of gun life(6) was taken.

24. Initially, curves of chance of hit with zero ranging errors were constructed for both velocities and both stages in gun life (Figures 6 and 7 are given as examples) and the effect of variation in range error as a permanent bias included. From these graphs the chance of hit with any sensible combination of weapon velocities and bias angle could be inferred. Next, the mismatch imposed by the ballistics of the HESH and RMG projectiles was examined and, assuming that zeroing would be carried out at 1200 yards, the values of range error between the points of strike of the two rounds obtained at all ranges (Figs. 8 and 9). From this information Figure 10, which shows the fall of shot of the RMG when fired with the HESH graticule, was constructed. Thus the range error at each target range could be ascertained and transferred back to the appropriate curve in Figures 6 and 7 and and the chance of hit obtained for that range. Here again, the oscillation with range of the chance of hit values is apparent but with higher frequency than that in the APDS case owing to the smaller range intervals used. Departures from the regular rise and fall of the chance of hit values occur at 1200 and 1700 yards in the 2300 f/s case and at 1200 and 1450 yards in the 2400 f/s case and, with both velocities, at about 1900 yards. Reference to Figure 10 shows that these divergences occur when the HESH and RMG shots fall either at the same range or at ranges which are multiples of 50 yards apart. When these coincidences occur, the regular increase and decrease of range error is altered and the corresponding chance of hit values do not follow the regular pattern.

25. All the chances of hit were calculated on the assumption that the gunner, in addition to interpreting the range information given by the RMG, would note the error in line caused by crosswind, tilt and other error sources, and suitably correct the lay of the main armament.

26. It is interesting to note from Figures 4 and 5 that the general effect of gun wear on chance of hit is small with the velocities considered. It appears from this that if due regard is given to the choice of velocities in a system whose performance is critically dependent on its weapon characteristics, then the deterioration in chance of hit as these characteristics change might be controlled.

27. Another effect that is apparent from Figures 4 and 5 is the degradation which can occur in chance of hit at ranges between 1800 and 2000 yards. This is due to the horizontal mismatch between the projectiles referred to in para. 15. If two projectiles are matched in this way, unless their ballistic characteristics are either identical or complementary, (i.e. the effects of differences between the ballistic coefficients are balanced by those of differences in muzzle velocity), then there is bound to occur a region where the horizontal mismatch is relatively large. In most cases, the position

of this region in the range band can be adjusted by changing the "bias" angle between the two weapons; in the case considered, performance at the longer ranges has been sacrificed to obtain increased chance of hit at the middle and lower ranges.

CONCLUSIONS

28. It is shown in the foregoing report that of the three types of fire control considered for use with the 105 mm. APDS projectile, the RMG and coincidence range finder do not offer much advantage one over the other, but both show a substantial increase of 20 - 30% in first round chance of hit over that given by visual range-finding.

29. As far as the HESH projectile is concerned, the RMG provides considerable improvement in first round chance of hit over visual range-finding (an increase of 70% at 1000 yards and 20% at 2000 yards) and gives a general increase of about 20% over that obtained using a coincidence range-finder. An exception to this can occur at the longer ranges where the chance of hit of the system using the RMG can fall to as much as 5% below that with the range-finder. This occasional deterioration is unavoidable when the present system is designed to give maximum performance at medium ranges and could only be overcome by including an extra graticule in the sight, a complication which would detract from a system whose simplicity is one of its major advantages.

30. It appears from the study of the effect of gun wear that in the case considered both weapons can deteriorate in such a way that the chance of hit of the system is unaffected. However, it is also possible that barrel wear could result in a serious degradation in chance of hit at later stages in the system life; this should be borne in mind in any development of systems which depend for their effeot on the control of one weapon by another.

ACKNOWLEDGEMENTS

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(2)	F.V.R.D.E. Report A.W. R.2	Demonstration and Trial of the machine-gun ranging technique for tank gunnery. M.E.L.F. April 1956.
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(4)	F.V.R.D.E. Report A.R. 179	A fire-control scheme for the new medium tank (F.V.4201).
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(7)	Frankford Arsenal Report R-1380A	Fire Control Studies: Tank gunnery accuracy evaluation (U).

APPENDIX

Summary of error sources for the Browning RMG and the 105 mm. Tank Gun: Line

	Error	RMG	105 APDS	105 HESH
Permanent Bias	Sight offset	- (Removed by sight)	- (Removed by sight)	- (Removed by sight)
	Drift	-	-	-
Variable Bias	Shooting - In error	A	A	A
	Alignment	A	A	A
	Throw-off, occ-occ	-	0.5' sd	0.5' sd
	Lateral bend, occ-occ	-	0.33' sd	0.33' sd
	Trunnion Tilt	4° 55' sd	4° 55' sd	4° 55' sd
	Cross-wind	4.9 f/s sd	4.9 f/s sd	4.9 f/s sd
Random Error	Ballistic error	0.262 % sd	0.246 % sd	0.296 % sd
	Lay, rd - rd	A	A	A
	Backlash in sight/gun	0.33' sd	-	-
	Wind gustiness	6.0 f/s sd	6.0 f/s sd	6.0 f/s sd

A = ARDE Report (B)6/58

APPENDIX

Summary of error sources for the Browning RMG and the 105 mm. Tank gun: Elevation

	Error	RMG	105 APDS	105 HESH
Permanent Bias	Sight offset	- (Removed by sight)	- (Removed by sight)	- (Removed by sight)
Variable Bias	Shooting - In error	A	A	A
	Alignment	A	A	A
	Mech. errors in sight system	A	A	A
	Jump	-	0.5' sd	0.5' sd
	Droop	-	0.33' sd (Thermal sleeve)	0.33' sd
	C_o, variations in air density	3% sd	3% sd	3% sd
	Gun wear	100 f/s drop for 2000 rds	70 f/s drop for 225 rds	35 f/s drop for 225 rds
	Charge Temp. (occ-occ)	12 f/s for 10°F sd	27 f/s for 10°F sd	4 f/s for 10°F sd
	Head-wind	4.9 f/s sd	4.9 f/s sd	4.9 f/s sd
	Range-finding. Visual	-	30% of range sd	30% of range sd
	Coincidence R/F	-	15 R^2 sd	15 R^2 sd
Random Error	Ballistic Error	0.262 $\sqrt{h}$ sd	0.276 $\sqrt{h}$ sd	0.296 $\sqrt{h}$ sd
	Propellant, lot - lot	25.6 f/s sd	14.8 f/s sd	3.0 f/s sd
	Charge temp, Rd - Rd	-	-	-
	Lay, rd - rd	A	A	A
	Backlash in sight/gun	0.33' sd	-	-
	Wind gustiness	6.0 f/s sd	6.0 f/s sd	6.0 f/s sd

A = ARDE Report (B)6/58

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FIG. 1

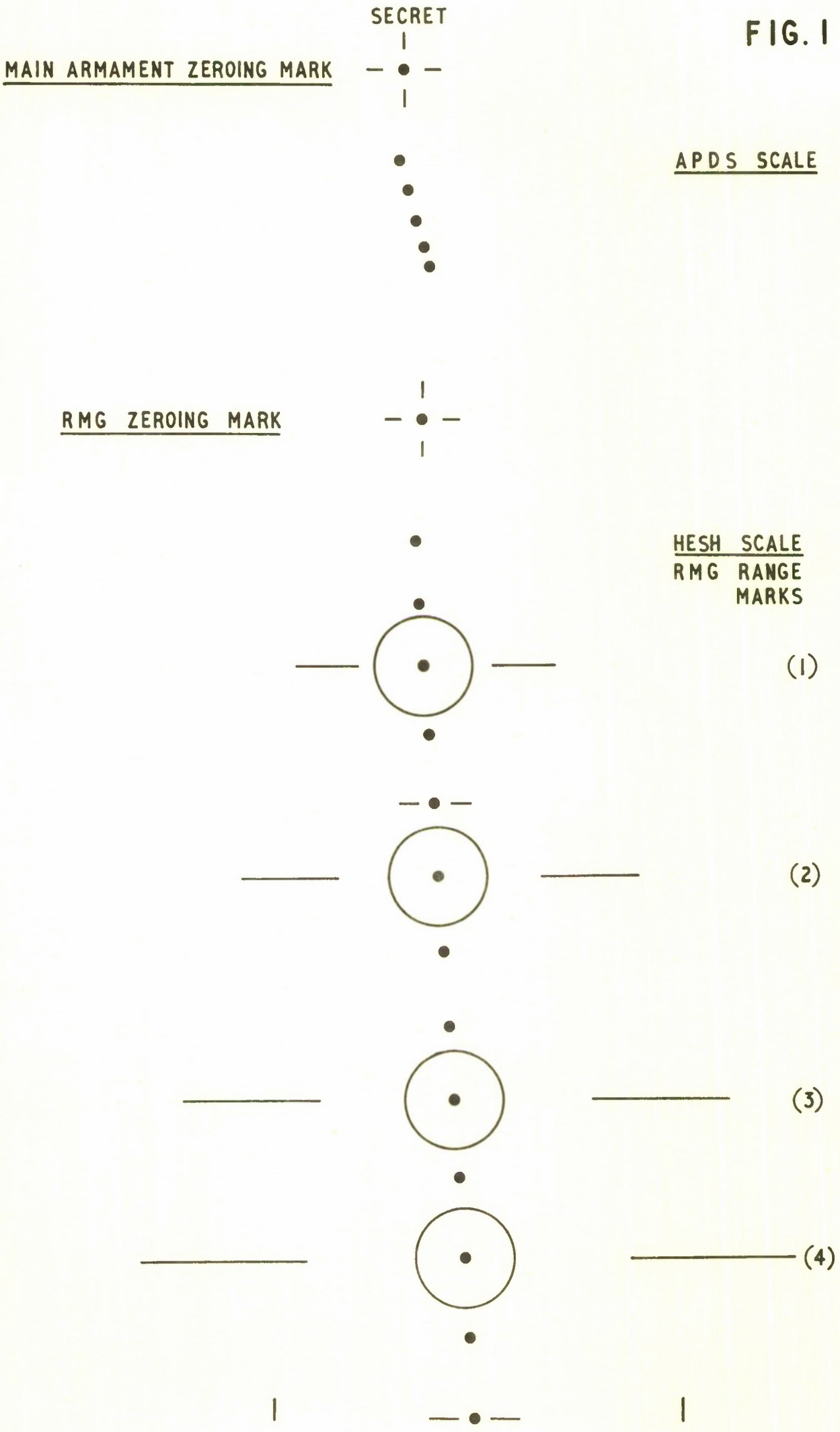

FIG. 1 SIGHT GRATICULES FOR USE WITH RMG, 105MM. APDS AND HESH.

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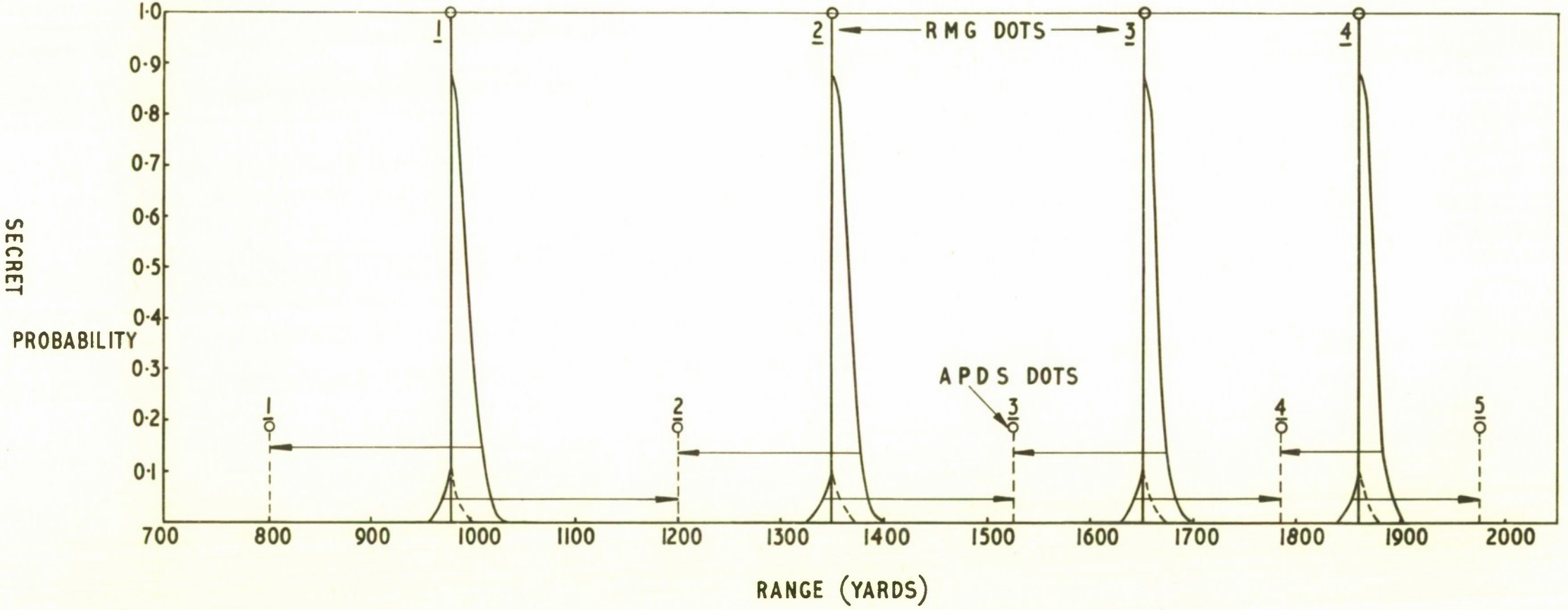

FIG. 2 THE PROBABILITY OF TAKING DIFFERENT APDS GRATICULE DOTS FROM THOSE SPECIFIED BY THE RMG RANGE BANDS.

FIG. 2

FIG.3

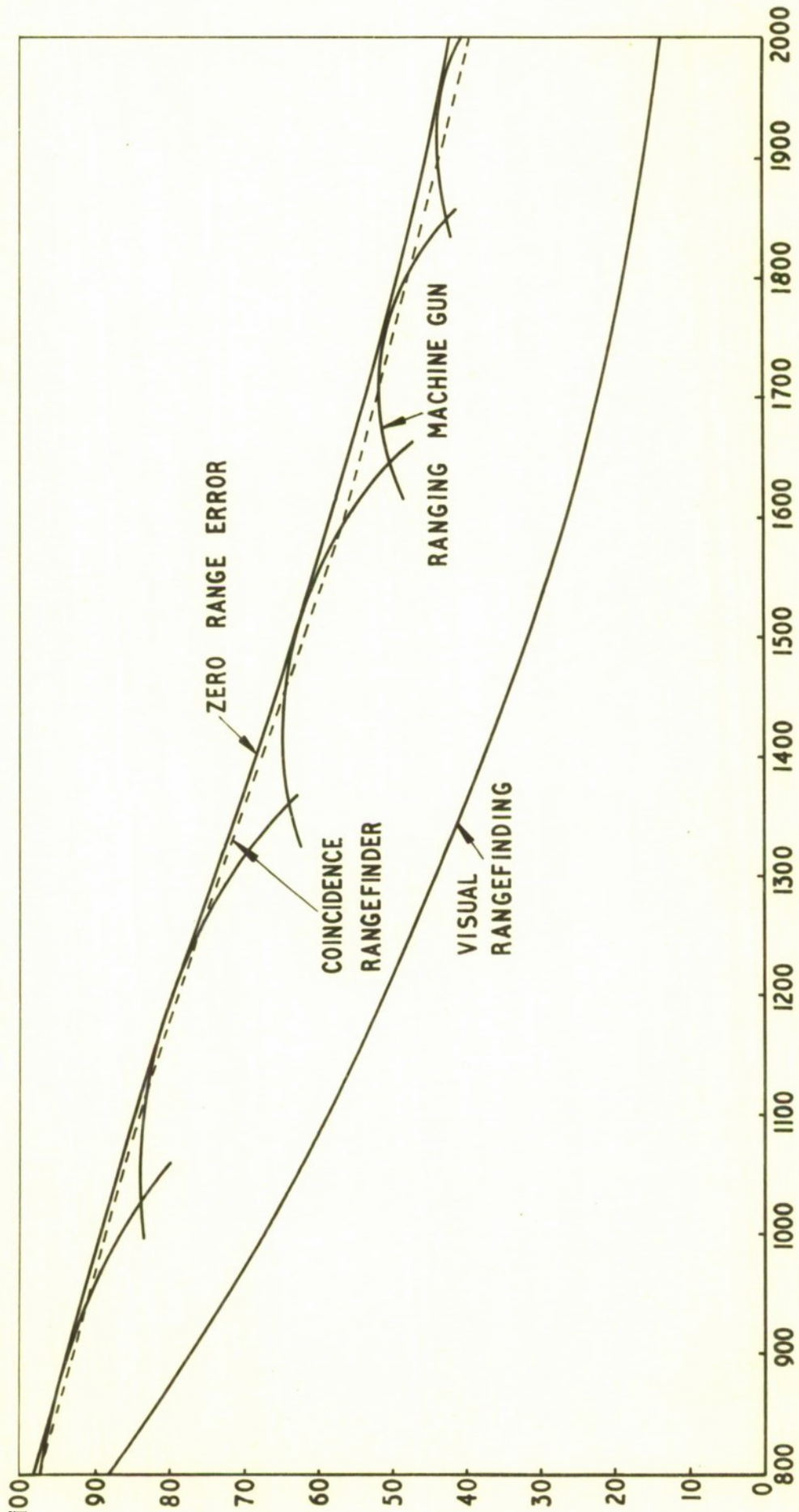

FIG. 3 CHANCE OF HIT OF THE 105 MM. TANK GUN (APDS)

FIG.4

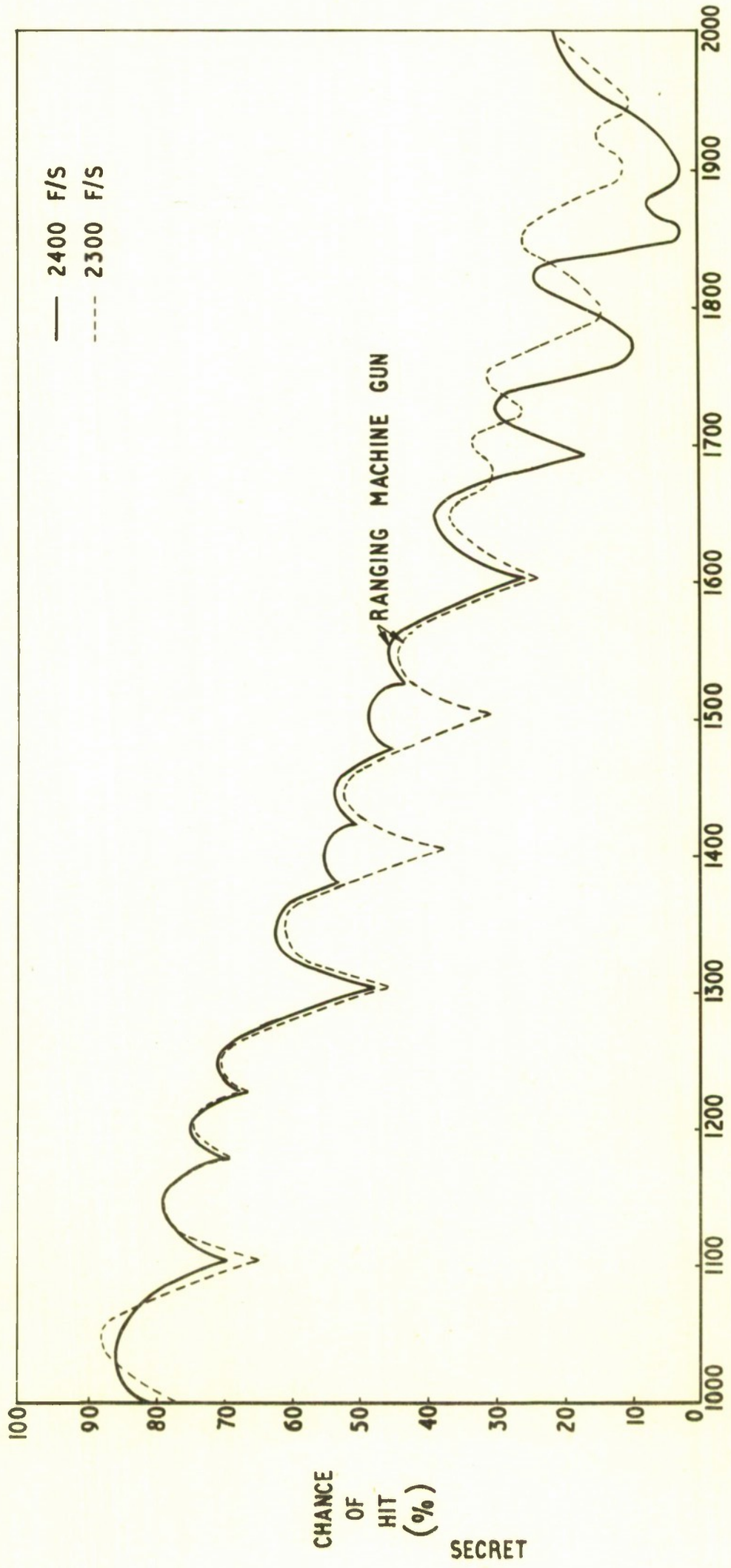

FIG. 4 CHANCE OF HIT OF THE 105 MM. TANK GUN (HESH): NO BARREL WEAR

FIG. 5

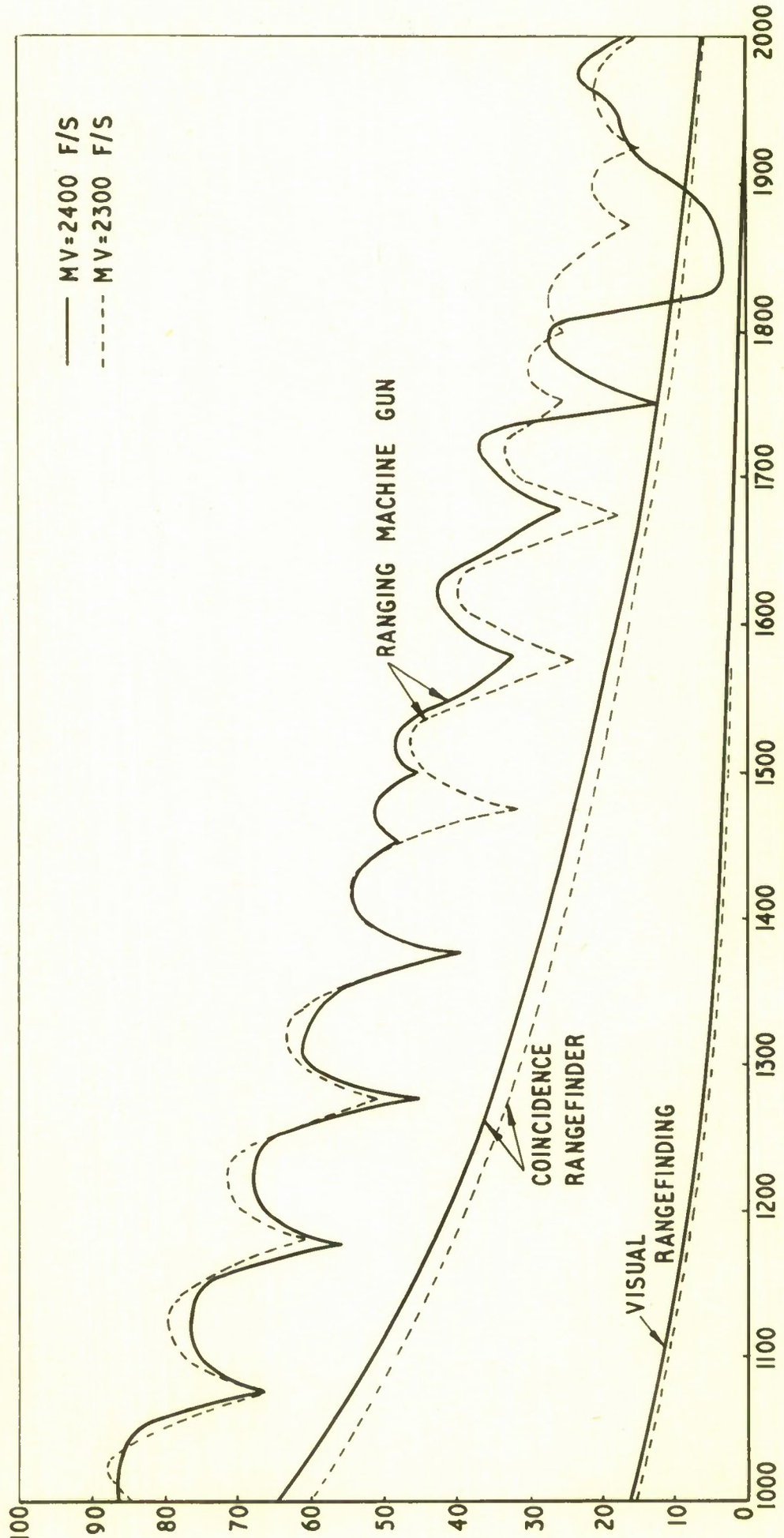

FIG. 5 CHANCE OF HIT OF THE 105 MM. TANK GUN (HESH): PART-WORN BARREL (25 FT/SEC DROP)

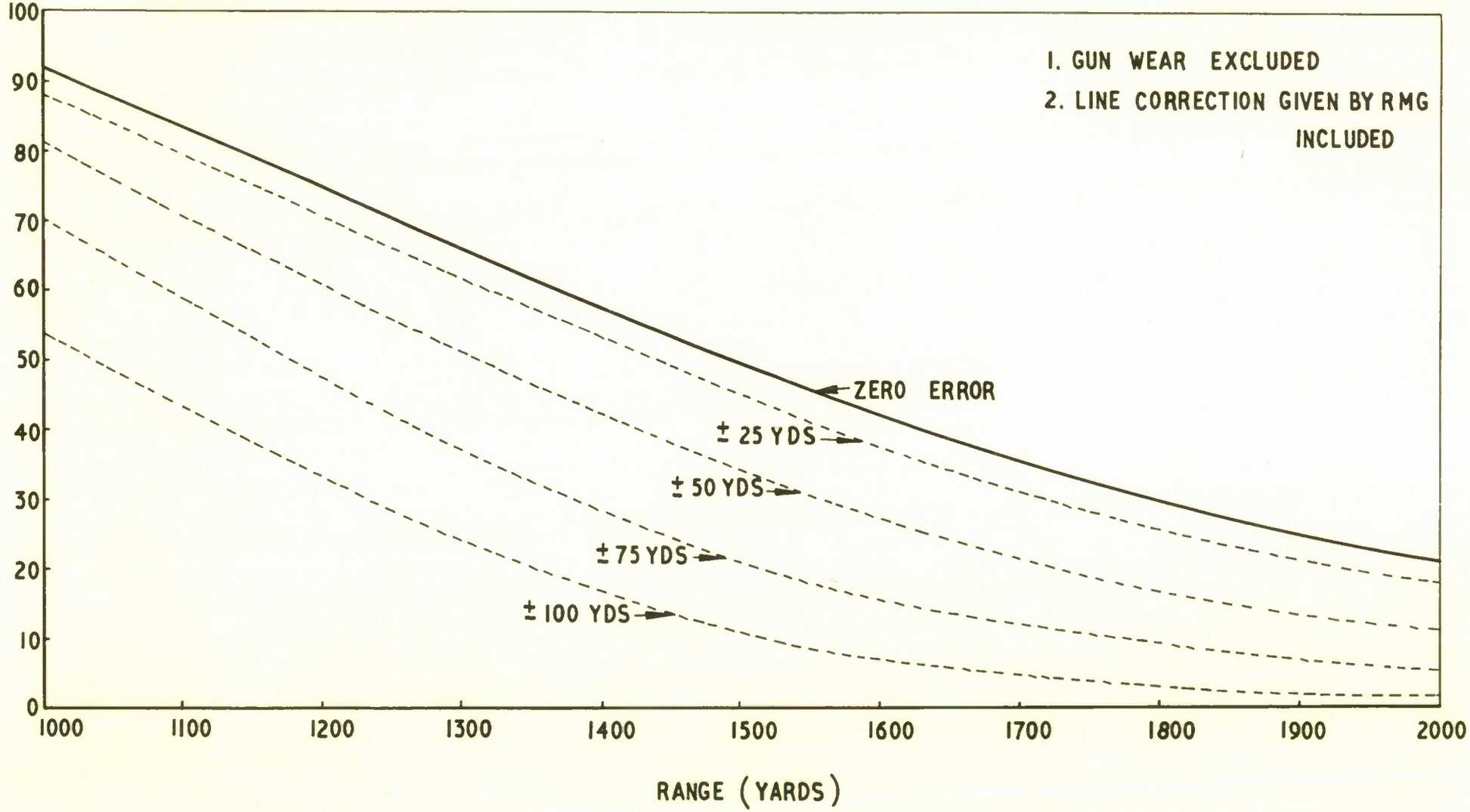

FIG. 6 THE EFFECT OF RANGE ERROR ON CHANCE OF HIT OF THE 105 MM TANK GUN (HESH : MV = 2400 F/S)

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FIG.6

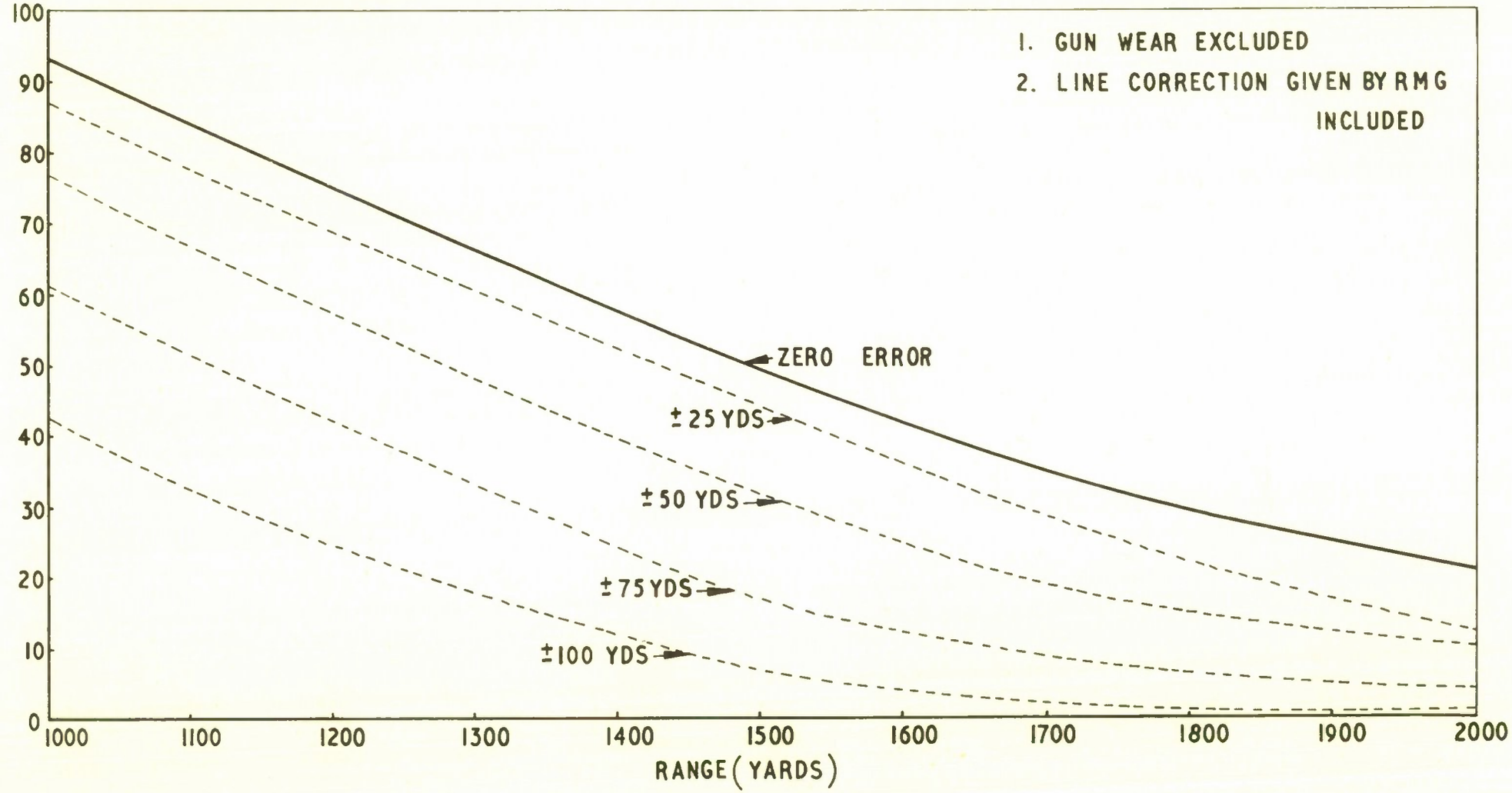

FIG. 7 THE EFFECT OF RANGE ERROR ON CHANCE OF HIT OF THE 105 MM TANK GUN (HESH : M V = 2300 F/S)

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FIG.7

FIG.8

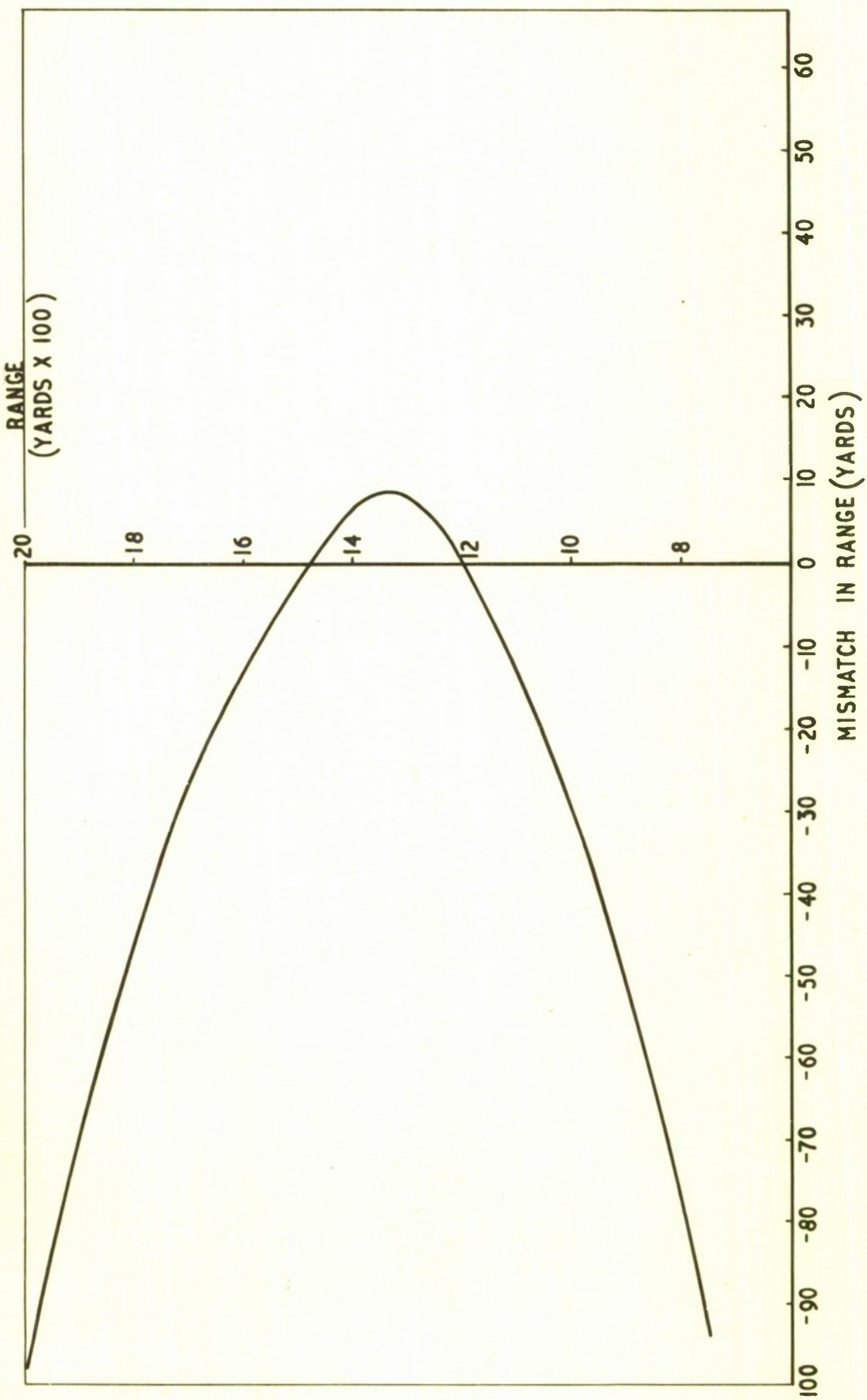

FIG. 8 MISMATCH IN RANGE BETWEEN THE RMG AND 105 MM HESH PROJECTILES (HESH MV=2400 F/S)
ZEROING RANGE = 1200 YARDS

FIG. 9

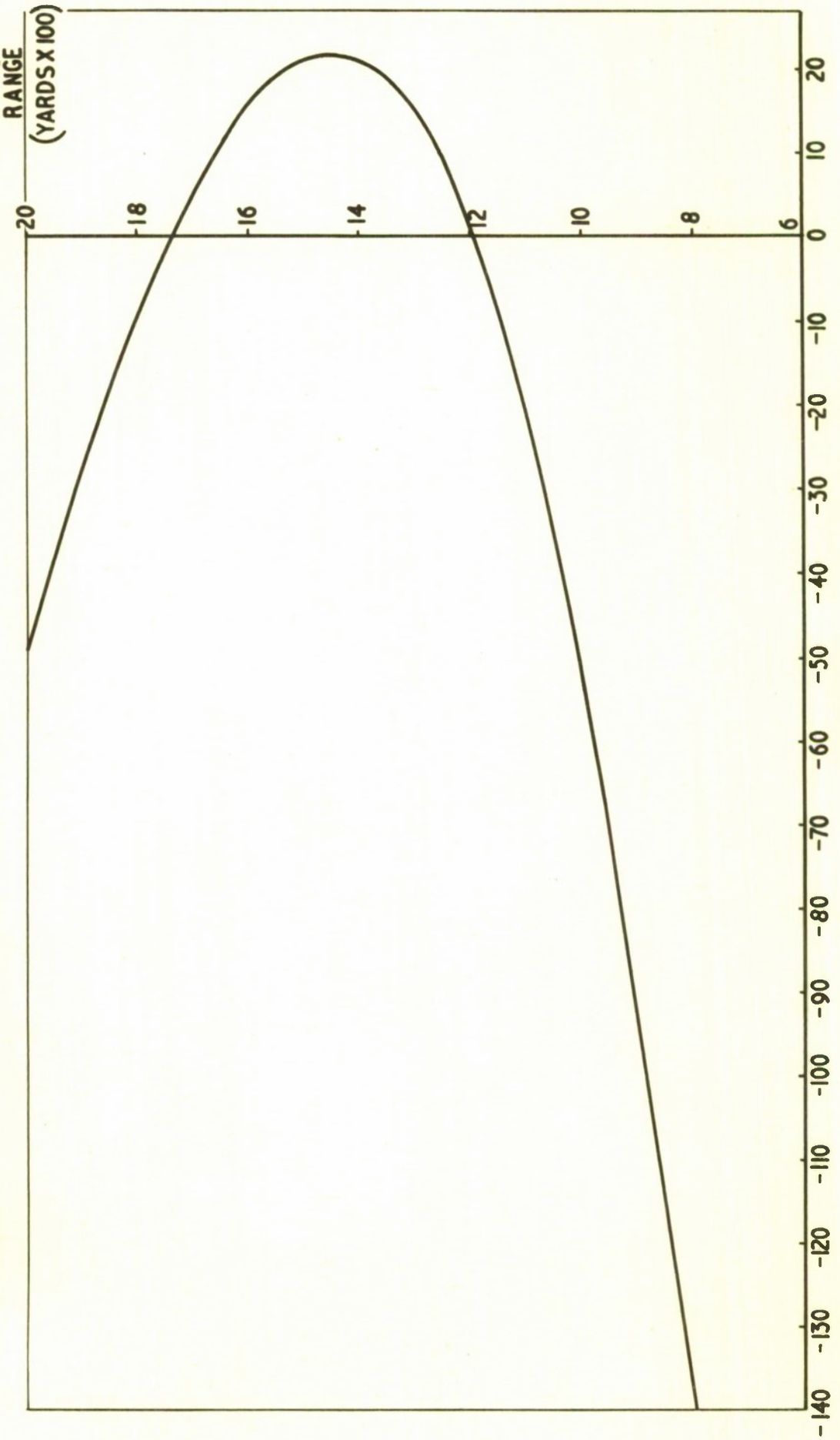

FIG. 9 MISMATCH IN RANGE BETWEEN THE RMG AND 105 MM HESH PROJECTILES (HESH MV=2300 F/S)
ZEROING RANGE = 1200 YARDS

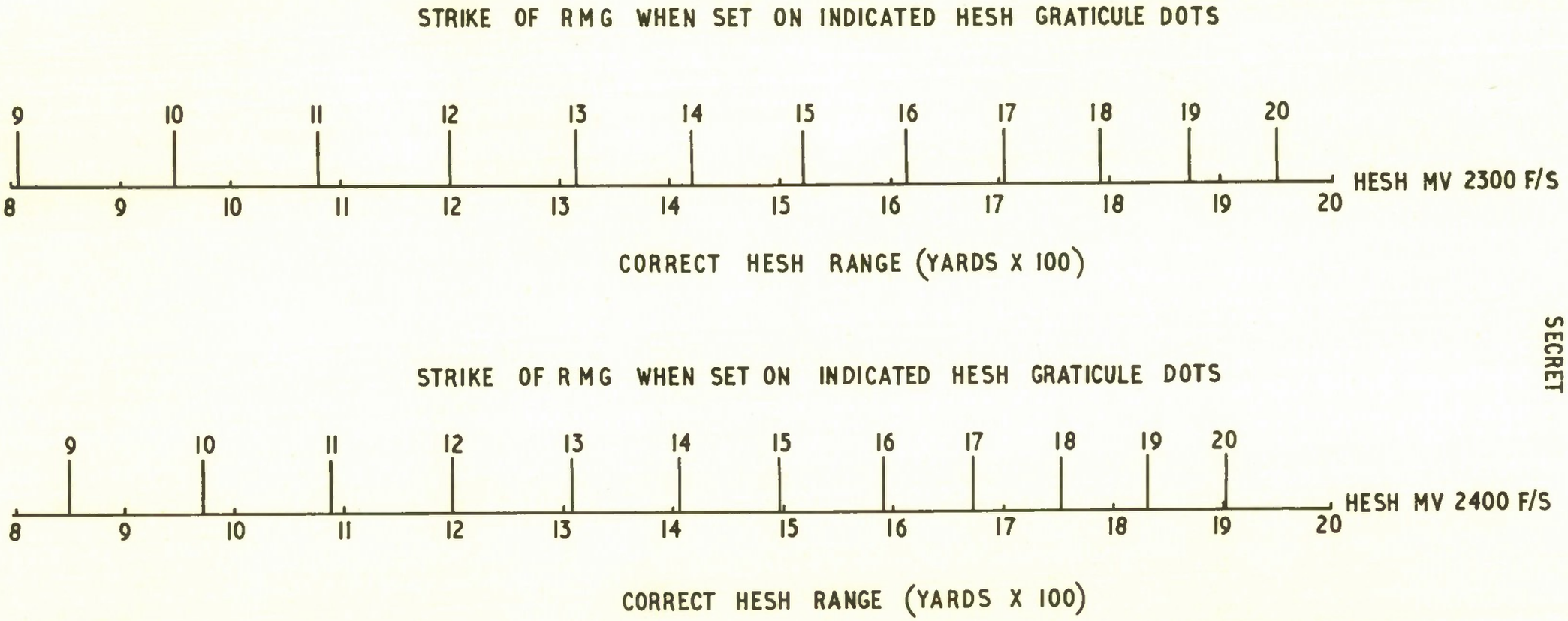

FIG. 10 RANGE ERROR OF RMG – 105 MM HESH SYSTEM WHEN ZEROED AT 1200 YARDS.

SECRET

FIG.10

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